

introduction to the centrifuge chamber. The effects of the temperature on the separation are shown in FIG. 17. Surprisingly, the reduction in temperature, even from 15° C. to 5° C., causes a significant redistribution of the SWCNT concentration in the solution. This redistribution generally improves the separation as discussed below.

**[0122]** Specifically, FIG. 17 presents photographs and apparent SWCNT length versus distance traveled curves showing the effect of temperature on the measured length separation performed at 3142 Rad/s. Performing the separation at lower temperatures improves the resolution of the fractions, as indicated by the increased slope of the apparent length values. The dashed curves display the fractional concentration, as measured by absorbance at 775 nm, for the displayed separations. The integrated concentration is the same in each experiment.

**[0123]** Plotting the fractional concentration profile versus fraction number for four of the different separation speeds shown in FIG. 14 in FIG. 18, it can be inferred that the plateau feature observed at higher separation rates is due to a mixture of different lengths in those fractions, and not due to a different spatial distribution of well resolved lengths. This is visible in the dramatic reduction in the concentration of the short SWCNTs in the fraction approximately 0.5 cm from the injection layer with the increase in the separation rate from 1257 Rad/s to 3142 Rad/s. The plateau feature in the higher rate separations is the result of this short material being mixed upwards in the liquid column, and reducing the average length of those fractions. 1257 Rad/s generated the steepest projected length curve under these conditions. Including the information of the relative concentration for each average length it is clear that this separation resulted in the greatest resolution of length in the different fractions. Integrating each of the concentration and length curves to calculate an average length value for the separated SWCNTs yields a value of  $225 \pm 5$  nm in each case, equal to the average length projected by UV-Vis-NIR absorbance for the unsorted material of approximately 220 nm.

**[0124]** Specifically, FIG. 18 illustrates concentration profiles (thin lines) from the absorbance at 775 nm versus the distance traveled for selected separations shown in FIG. 13, and the UV-Vis-NIR projected length values (bold lines) from the same separations. The slower separations yield fractions of smaller width as evidenced by the change in the concentration curves while remembering that the injected dispersion was identical in all four experiments. Integration of the curves to calculate the initial average length yields a common value  $225 \pm 5$  nm for all of the curves.

**[0125]** A comparison of the measured average length versus distance traveled curves from the 1257 Rad/s separation to the simple theory in equation (4) is shown in FIG. 17. The expected functionality given by equation (4) is seen in the more resolved 1257 Rad/s separation, although the theoretical curve is shifted in position toward further traveled distance. The most likely cause for this disagreement is the downward motion of the iodixanol polymer in response to the applied centripetal acceleration. This motion has been modeled using the Lamm equation by both Arnold et al and Nitish et al. in predicting the final position of SWCNTs during isopycnic (chirality) separation using ultracentrifugation. In both literature results, the redistribution of the iodixanol is significant with centrifugation. Due to the strong absorption of the iodixanol, it was determined that the uppermost two to four fractions are significantly depleted (up to 70% for the top

fraction), and the bottommost fractions, numbers 14, 15 and 16, increase significantly in iodixanol concentration, during centrifugation. This demonstrated redistribution, would affect the translation of the SWCNTs in the same manner that a body traveling against a moving flow is affected; an outside observer measures significantly less motion in the static reference frame than is experienced by the traveling body. Empirically shifting the theoretical curve demonstrates that the shape of the measured average length values is consistent with the theory.

**[0126]** Specifically, FIG. 19 compares the measured average length in each fraction for the 1257 Rad/s separation shown in FIGS. 7 and 8 with the theoretical prediction of equation (4). Assuming only equation (4), the theory qualitatively predicts the shape of the separation, but does not quantitatively predict the actual positions of the separated SWCNTs in the experiment. However, equation (4) assumes that the reference frame for the motion of the SWCNTs is the centrifuge tube. A more accurate description of the physics must include that the density medium is also pelleting during centrifugation. Downward drag from the pelleting iodixanol would, to first order, shift the separation curve to less distance traveled. A uniformly shifted curve matches the experimental data for a SWCNT-surfactant shell diameter of approximately 7.5 nm. There are two sets of possible explanations for the observed behavior of the SWCNTs with the separation rate: theories based on SWCNT initiated effects, and theories based on environment initiated effects. Examples of environment initiated effects would include generation of a sedimentation potential due to the centrifugation rate dependent rearrangement of the surfactant and iodixanol molecules, driven changes in the surfactant micelle structure due to the intensity of the induced pressure gradient, or generation of convection due to vibrations. SWCNT initiated effects could include concentration dependent association or aggregation, or alignment effects due to the gradient in centrifugal acceleration. The experiments detailed above allow the elimination of some of these possibilities. Given the noted results, it appears unlikely that external influences from the centrifuge are the cause of the mixing phenomenon. Identical separation at 3142 Rad/s is observed using either the  $\frac{3}{8}$  inch or 1 inch diameter centrifuge tubes indicates that vibrations or large flows are not likely causes of the observed behavior. Furthermore, the induction of an apparently similar mixing effect to that observed with an increase in separation rate by increasing the density of the layers at 1257 Rad/s implicates that the effect is intrinsic to separation parameters and is not externally generated. Likewise, the lack of change with the addition of 20 mM NaCl indicates that charge effects are unlikely to be the cause of the mixing behavior.

**[0127]** FIG. 20 illustrates redistribution of iodixanol during centrifugation. Bars on the points represent the width of the measured fractions within the centrifuge tube. The upper fractions lose significant amounts of iodixanol due to its downward sedimentation. However, the large size of the race layer allows the initial density to be approximately maintained for several cm above the SWCNT injection layer. This measurement was performed on a sample containing no SWCNTs in the injection layer, but that was otherwise identical in preparation. Additional drag on the oppositely traveling SWCNTs is expected due to this sedimentation.

**[0128]** The economic value of the preferred embodiment centrifugation process is significant. An estimate for the cost per mg of the separation process for the centrifugation tech-